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6 THE MANUFACTURE OF LIGHT-WEIGHT, RIGID SPHERES.

10 F.V. Weeks

SUMMARY

This memorandum outlines the approach made to satisfy the need for light-weight, radar reflective spheres. The development of polyurethane spheres coated with special electrically conductive paint and polyester resin copper plated spheres is described.

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1. INTRODUCTION

Effects of the atmosphere on the flight of an artillery shell require measurement of the relevant atmospheric conditions on a routine basis. Since The present method using standard meteorological sounding techniques, has a number of disadvantages, ~~and in 1974~~ W.R.E. investigated the feasibility of using a passive falling sphere to provide the required data ~~(ref.1)~~.

In 1975, W.R.E. undertook the task of considering the Application of the Falling Sphere Technique to Artillery Meteorological Systems ~~(AFSTAMS)~~, with the study to be carried out in two phases: (1)

Phase I

The development of a radar reflective, precision sphere to a desired weight, size and surface finish. The spheres were to be instrumented and dropped from a meteorological balloon to check the data received against known meteorological conditions. and (2)

Phase II

The development of a sphere suitable for firing from an artillery cannon or rocket.

This report deals with the mechanical manufacturing problems and their solutions for the 330-mm diameter smooth, radar reflective spheres developed in Phase I. These housed telemetry to record skin temperature, and heater wires to ensure that the sphere was at ambient ground temperature when released at the appropriate altitude. At a later stage, 120-mm spheres of various weights were required with added constraints on the quality of the surface finish. Reference 2 describes the trials at Woomera and results obtained using these spheres. cont on P.B

2. DEVELOPMENT OF PROCESS FOR 330 mm SPHERES

The specification for the spheres was fairly stringent. They were to be 330 mm in diameter ± 1.55 mm, with an all-up weight of no more than 500 gm including heaters, telemetry and batteries. The surface was to be smooth and free from all pitting, be radar reflective and be electrically conductive to act as the telemetry aerial.

Weight being a major criterion, the material first considered was polystyrene foam beads. The minimum density of commercially available polystyrene foam blocks is 12 kg/m^3 resulting in an acceptable sphere weight. This process requires a supply of superheated steam for expanding the polystyrene beads to achieve the optimum density of the foam; this was not available in the laboratory. The solvent in the silver conductive paint proposed as an external coat for radar reflection was found to dissolve the polystyrene foam. The necessary heater wires would have had to be moulded in position, and a cavity for installation of telemetry cut into the sphere after moulding. This would have defected the surface finish which was most important. For these reasons the use of polystyrene foam was not further considered.

As an alternative, a two part mix of an ICI Polyurethane foam was selected, Deltalac GPI and Supersec DN/R. As the density of this material was higher than polystyrene foam, the manufacture of a hollow sphere became necessary.

3. MANUFACTURING TECHNIQUE FOR 330 mm SPHERES

Having established the moulded density of the chosen material, calculations based on the required sphere weight resulted in a hollow shell of 6 mm wall thickness. In order to install equipment internally in the spheres, it was decided to mould the spheres in two halves subsequently spigotted together and glued. Male and female wooden moulds were used for production of the hemispheres (figure 1). Experience dictated that, in order to produce a smooth external surface free from pitting, the mixture be poured into the female half, brushed up the walls and the male half quickly inserted. The joint line being uppermost, the male half was provided with a number of riser holes to ensure release of trapped gas.

Liquids or grease used as release agents, contaminated the surface of the foam causing the cells to collapse during the polyurethane foaming process, resulting in a hard honeycomb outer skin. Araldite QV10 proved to be the best release agent tried, since it did not melt under the exothermic heat generated during foaming, as did other waxes.

Heater wires required for temperature control of the sphere were first installed by moulding straight into the polyurethane foam wall. The foam, being an excellent insulator, did not conduct the heat away rapidly enough with the result that the local temperature of the foam increased to such a degree that it started to burn. It was then decided to bond the heater wire to the inner surface of the hemispheres using a silicone rubber, Rhodosil CAF1 elastomer. By this method, the heat was dissipated away from the wire and distributed over a 9 mm wide strip, (the width of the bonding silicone rubber), and found to be quite acceptable (figure 2).

After the heaters were bonded in place, and the aerial slot was masked (figure 3), the hemispheres were sprayed with 2 coats of an electrically conductive paint, (Technit 72-00025, silver particles suspended in an acrylic base). After the installation and checking of telemetry and thermistors, the hemispheres were glued together, using the female mould as a jig to ensure perfect matching at the joint line. To assist in location, a spigot and recess were moulded around the joining faces (figure 4). Any excess glue was removed after the sphere was taken from the mould, and the joint line then spray-painted with electrically conductive paint to ensure electrical continuity between the two hemispheres.

In the initial cold chamber tests, the joint line between the two hemispheres cracked. This was believed to be due to the temperature of -60°C at the simulated altitude of 20 km. At this temperature, the fast curing epoxy resin initially used for bonding the hemispheres became so brittle that when the internal heaters were turned on, the differential expansion between the foam and epoxy resin caused a failure at the bond line. This was overcome by using a more flexible epoxy resin (Araldite retail pack) and removing the foam skin at the joint, thus enabling the resin to penetrate into the foam structure.

4. DEVELOPMENT OF PROCESS FOR 120 mm SPHERES

The specification for the 120 mm spheres was similar to that for the 330 mm spheres. They were to be 120 mm diameter ± 0.5 mm but with varying weights in the order of 100 gm, 150 gm and 200 gm. The surface was to be radar reflective, smooth and free from flaws or pitting, but provision for telemetry and heater wires was not required.

Reasonable success in the production of the 330 mm diameter spheres prompted the use of the same materials for the 120 mm diameter spheres. The 120 mm diameter and maximum weight of 200 gm allowed a solid polyurethane ball to be moulded by a technique much simpler than that used for the 330 mm diameter sphere. The foam of the required weight was poured into a split aluminium mould through

a small gate, which was plugged during the foaming period. The solid spheres so produced were of poor quality with gas bubbles trapped in the surface. Further samples were produced where the foam was allowed to bleed off through the gate before being plugged, with no marked improvement. In an effort to improve the surface finish, the two halves of the mould were painted internally with polyurethane foam to form a skin cured at ambient pressure. The mould was then assembled and spheres foamed as before. However, since the mould was now sealed, the core foamed and cured under pressure. Shortly after removal from the mould, ripples appeared on the surface of the spheres and hand dressing and then repainting were required. Tests on the 330 mm diameter spheres had shown that the smoothness of the painted finish was marginal, so copper plating was considered for the smaller 120 mm spheres. Attempts to copper plate the spheres proved unsatisfactory; not only did the plating fluid seep into the porous foam, increasing the weight beyond the allowable limits, it also caused corrosion around the small pin holes in the surface, and the finish was therefore not electrically acceptable.

Because of the failure to copper plate the polyurethane foam satisfactorily, the next step was to try and improve the surface finish of the painted foam. This was done by first painting the inside of the mould, prior to pouring the foam, with Technit silver paint as used on the larger hollow spheres. Whilst this showed some prospect of success, two or three coats were required and these tended to delaminate when being extracted from the mould. Due to the short time scale for the completion of the task, and the problems requiring attention, the use of polyurethane as a material for the 120 mm diameter spheres, was abandoned.

Copper plated Epoxy or Polyester resin spheres were next considered, Polyester was ultimately chosen because of its fast curing time at room temperature compared with Epoxy. With this type of material, the final surface finish of the sphere would be equal to the surface finish of the mould. "Polylite 61-303" was the material used. However, in order to produce a hollow sphere, required by the weight limitations of 200 gm, it was necessary to continuously rotate the mould during the curing stage.

The aluminium mould consisted of two halves, having a hemisphere machined into each half and the two spigotted together to ensure alignment (figure 5). The moulding surfaces were highly polished to ensure ease of release and an acceptable surface on the finished Polyester sphere. To ensure minimum flash on the split line, care was taken to maintain sharp edges where the two hemispheres joined. In practice, it was found that at the joint there was 0.04 mm flash which was removed by hand during preparation for plating. The final operation of copper plating resulted in sphere of acceptable surface finish and electrical properties.

5. MANUFACTURING TECHNIQUE FOR 120 mm SPHERE

In order to simplify the process of continuous rotation of the mould during curing of the polyester, a piece of equipment was produced, which, for want of a better name, has been called a Tumble Jig (figure 6). The complete assembly, including the mould, was fitted on a lathe which provided the motive power.

A shaft is fitted to each half of the mould, the axes passing through the centre of the spherical cavity and located in bearings in a yoke held in the lathe chuck, the axis of rotation of which also passes through the centre of the spherical cavity. Attached to one end of the shaft is a friction driven conical wheel driven against a stationary rubber faced angle plate clamped to the bed of the lathe (figure 7). The size of the friction wheel is such that for each revolution of the lathe chuck, the friction wheel turns approximately one-half turn. This ratio being not exactly 2:1 the resin pool in the mould cavity varies its run, thus wetting the entire surface.

5.1 Theory of the tumble jig

Rotating the spherical mould in a jig simultaneously about two axes at 45°, slowly enough to allow the liquid resin to lie in a pool at the bottom of the jig, has the effect of continually wetting the walls of the mould with resin.

Consider rotation about the Q axis only (figure 7(a)). As the mould rotates, the pool of resin passes over the shaded area, and some of the resin adheres to the surface. Now rotate through 180° about the X axis and consider rotation again about the Q axis. The shaded (wetted) area is now at the top and the unshaded area is being wetted by the resin pool (figure 7(b)). By rotating the sphere in both planes at the same time, all parts of the surface of the sphere are repeatedly in contact with the resin pool, building up a shell until such time as the material no longer flows.

5.2 Speed of rotation

The mould must rotate slowly enough to ensure that the resin pool is always at the bottom of the spherical mould. If rotated too fast, the pool will be centrifuged into a continuous ring about one of the two axes of rotation, or a resultant of the two combined movements. Figure 8 shows the results of too high a tumbling speed.

The rotation speed about the X axis was varied between 2 and 34 rev/min. The best results for a 120 mm diameter sphere were obtained at 8 rev/min. This speed will vary with the diameter of the sphere.

The gel to cure time of the resin is approximately 20 min depending on ambient temperature, mass of resin in the mould and amount of catalyst used. It was found that if rotated too slowly, (less than 6 rev/min) the resin would gel and cure before all the surface area of the sphere could be wetted by the resin pool thus causing thick and thin sections in the wall.

It was found that catalyst in excess of 1% caused the resin to gel too quickly and the tumbling action built up the gelled resin into large balls on inner surface (figure 9). To overcome this problem, an epoxy resin could be used, but this would limit the production to one sphere per day, where two and three spheres were produced per day using Polyester resin.

5.3 Ratios of axial rotation

Axial rotation speeds in relation to each other were also varied. The first tried was with the mould rotating about the Q axis 3 revolutions to 1 revolution about the X axis. This resulted in a 7.85 thick ring around the equator of the Q axis, thinning out to 1.09 mm thick at the poles. The size of the friction drive wheel was then increased to give a 1 to 1 ratio. This still resulted in a thick section around the equator of the Q axis, but it was now much reduced. The friction wheel was further increased so that rotation about the X axis was 2 revolutions for every 1 about the Q axis. This gave quite acceptable results with only a slight difference in thickness between the poles and equator.

5.4 Quantity of resin

The larger the quantity of resin, the better the coverage and more even the thickness achieved. The minimum amount of resin to completely form the 120 mm diameter sphere was found to be 68 gm. Because of the tumbling action, there is a slightly larger amount of resin at the friction wheel end, so when less than the minimum amount of resin is used, an incomplete surface coverage occurs at the opposite pole, leaving a hole that becomes larger as less resin is used (figure 10). The quantity of resin in this particular project was governed by the weight of the spheres required; these range from 100 gm to 200 gm.

5.5 Release agent

To facilitate release of the sphere, the internal surface of the mould is covered with a silicone wax. Apart from preventing the liquid resin from wetting the surface of the mould, it prevents the resin from running freely over the surface of the mould and forming globules if insufficient resin is used.

5.6 Copper plating

The process for copper plating of epoxy and polyester spheres, is described in W.R.E. Process Bulletin PB77(ref.3).

6. CONCLUSIONS

Several spheres of 330 mm and 120 mm diameter have been manufactured and used in free fall experiments at Woomera.

It has been found that the 330 mm diameter spheres are unsuitable for sounding the atmosphere of interest to artillery, since the painted surface could not provide the finish required by aerodynamic constraints(ref.2). However, these spheres have since been found most useful for the calibration of surveillance radars.

Using the tumble jig manufacturing technique for the smaller diameter spheres, structures of high dimensional precision and very low surface roughness have been produced. Flight tests have shown that the spheres maintain stable aerodynamic behaviour, thereby providing a useful tool for sounding the lower atmosphere.

The tumbling manufacturing technique can be applied to the production of spheres of various sizes and weights, being limited only by the capacity of the driving lathe. This technique was found to be a cheap and efficient process to produce spheres for the AFSTAMS task.

7. RECOMMENDATIONS

Further development must now be done to strengthen the sphere to enable it to withstand the high accelerations experienced during firing from an artillery piece. Accelerations of the order of 10 000 g can be expected.

It is recommended that the skin be reinforced with glass cloth and a more flexible epoxy resin be used instead of the weaker brittle polyester resin that is being used at present. Also, a honeycomb or foam structure could be considered to support the sphere during acceleration.

It is important that these reinforced spheres still meet the same requirements of weight, size and surface finish in order to maintain the flight performance already established.

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No.	Author	Title
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2	Johnson, S.G.	"Application of Falling Sphere Technique to Artillery Meteorological System". (AFSTAMS) Report on Phase I of Task. WRE-RE-1665 (WR&D), September 1976.
3	Day, B.	"Copper Plating of Epoxy and Polyester Spheres". W.R.E. Electro Finishing Section Process Bulletin PB77.
4	Tindal, N.	"The Design and Development of the Instrumentation for an Ultra Light Weight Telemetered Sphere". WRE-TM-1639 (WR&D), July 1976.

Figure 1. 330 mm diameter sphere mould with moulded polyurethane hemisphere

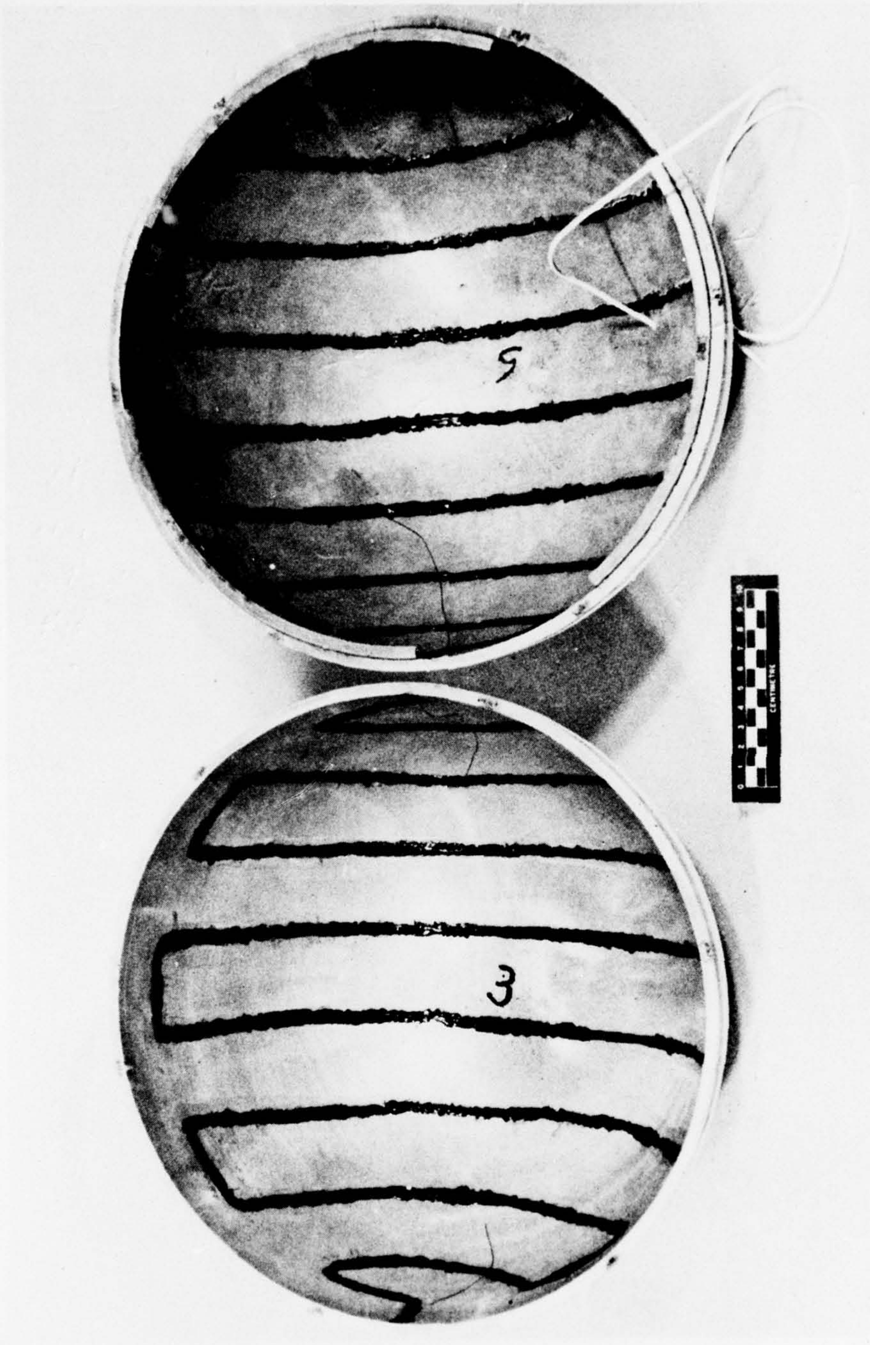

Figure 2. 330 mm polyurethane sphere with heaters

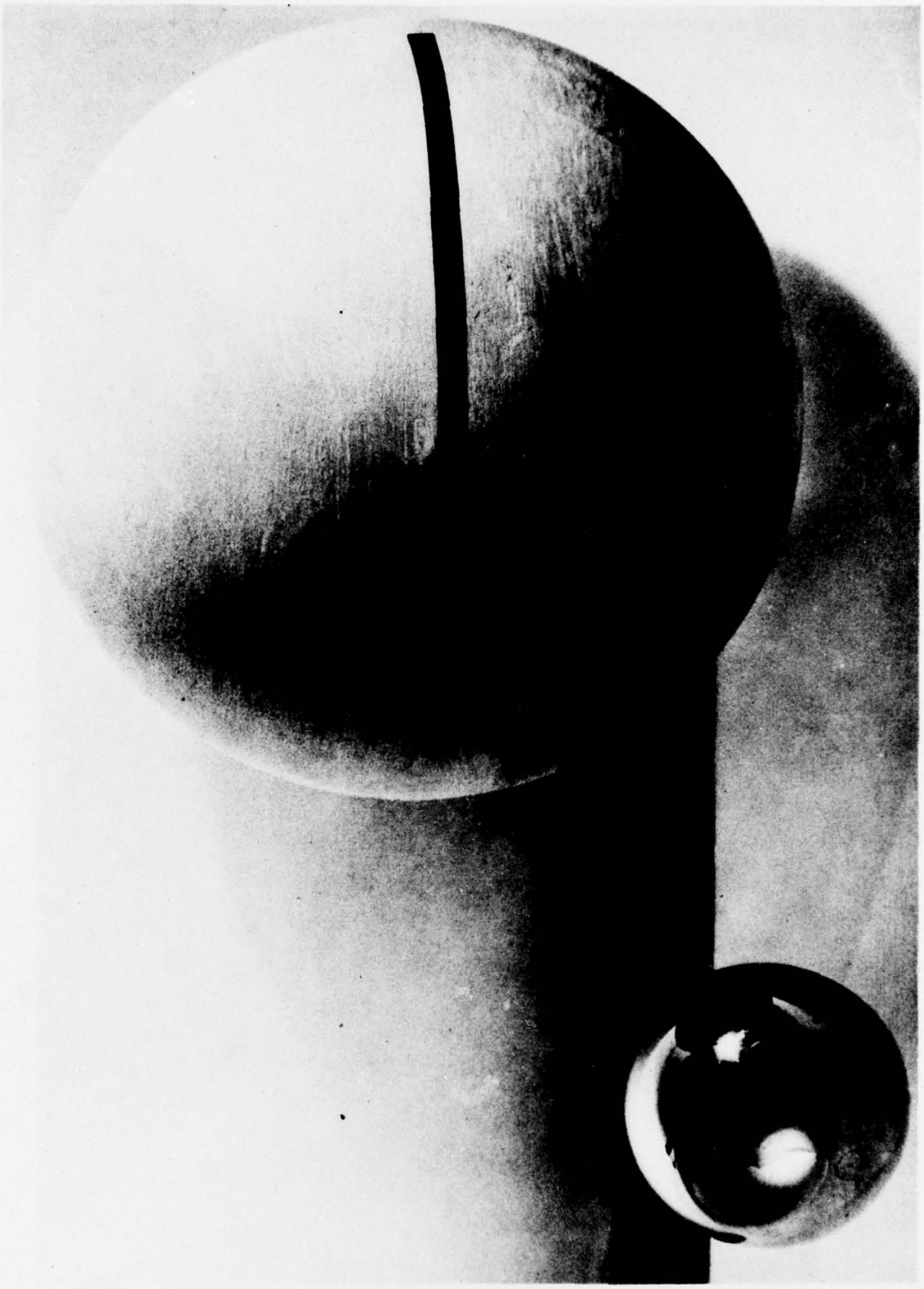

Figure 3. 330 mm diameter sphere coated with silver acrylic paint showing aerial slot
120 mm diameter sphere. Copper plated.

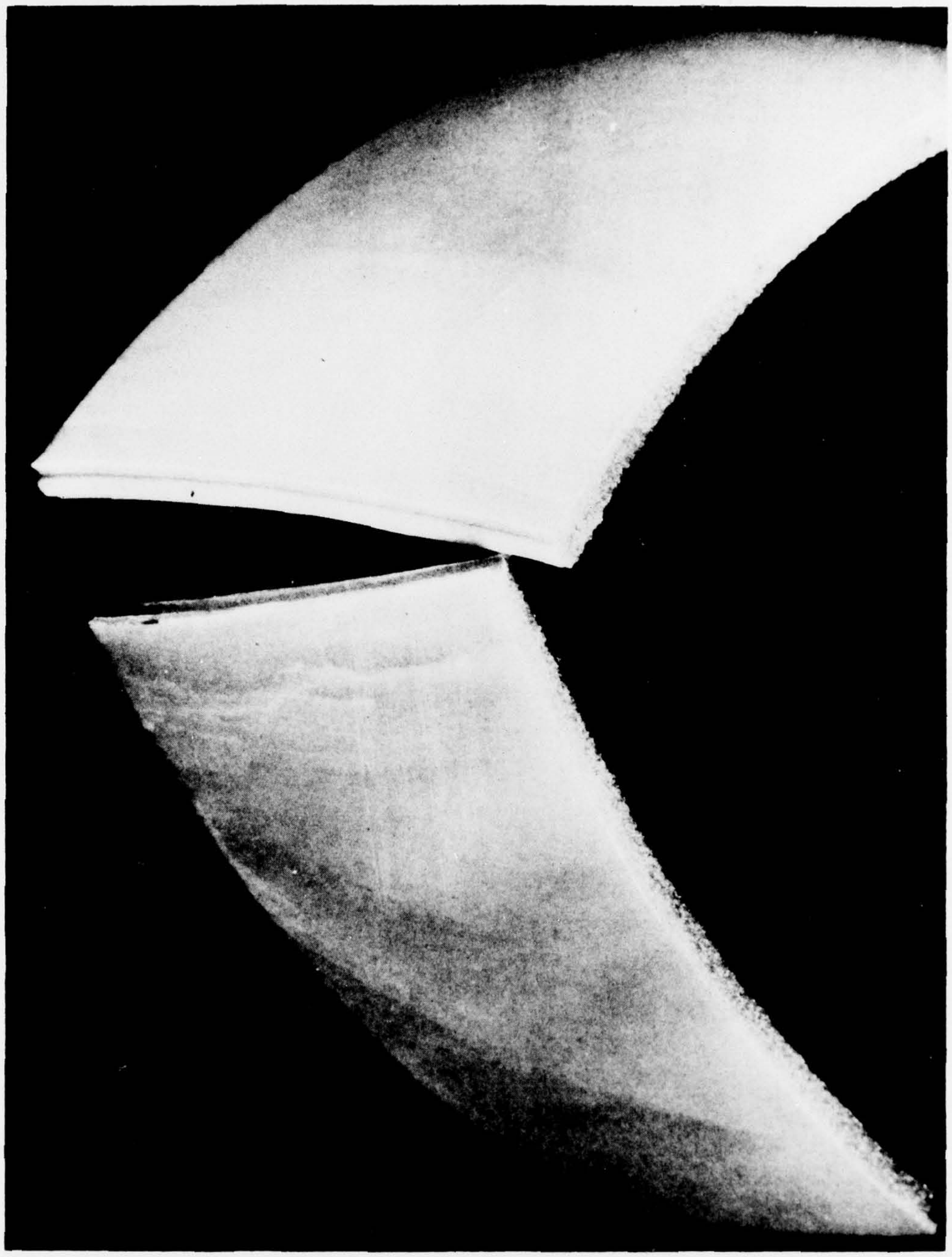

Figure 4. Spigot joint used to locate 330 mm polyurethane sphere halves

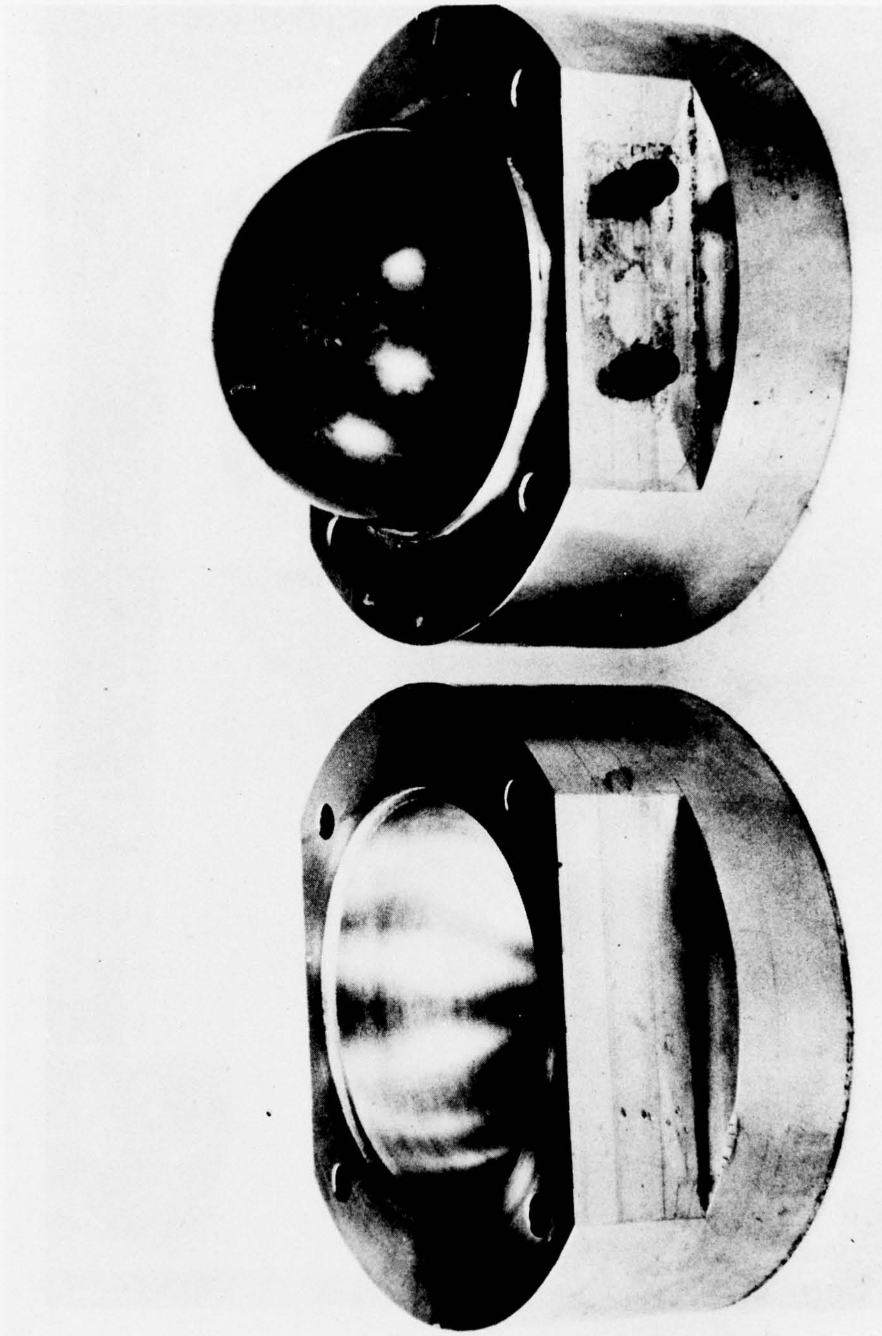

Figure 5. 120 mm diameter sphere mould

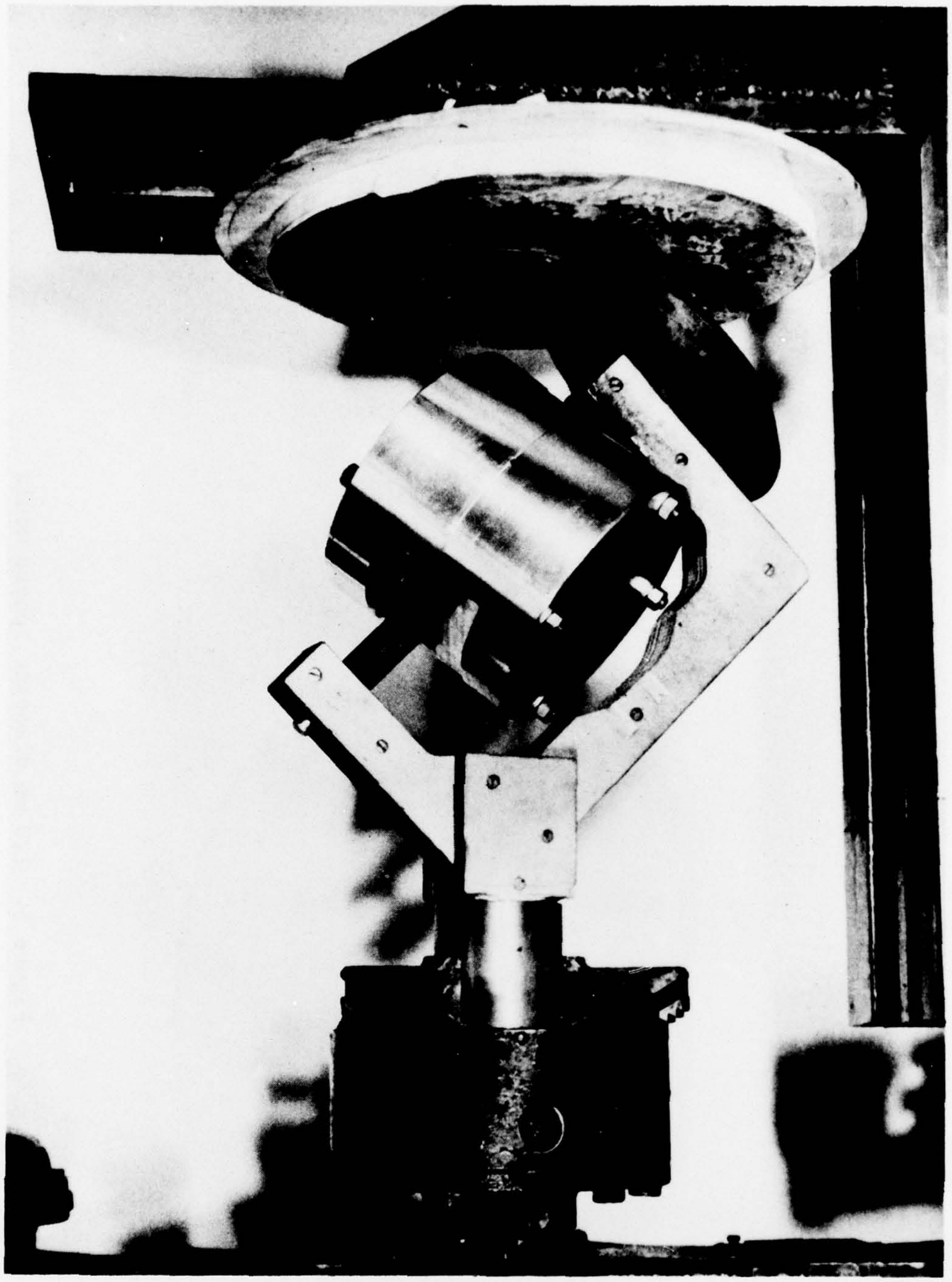

Figure 6. Tumbling jig

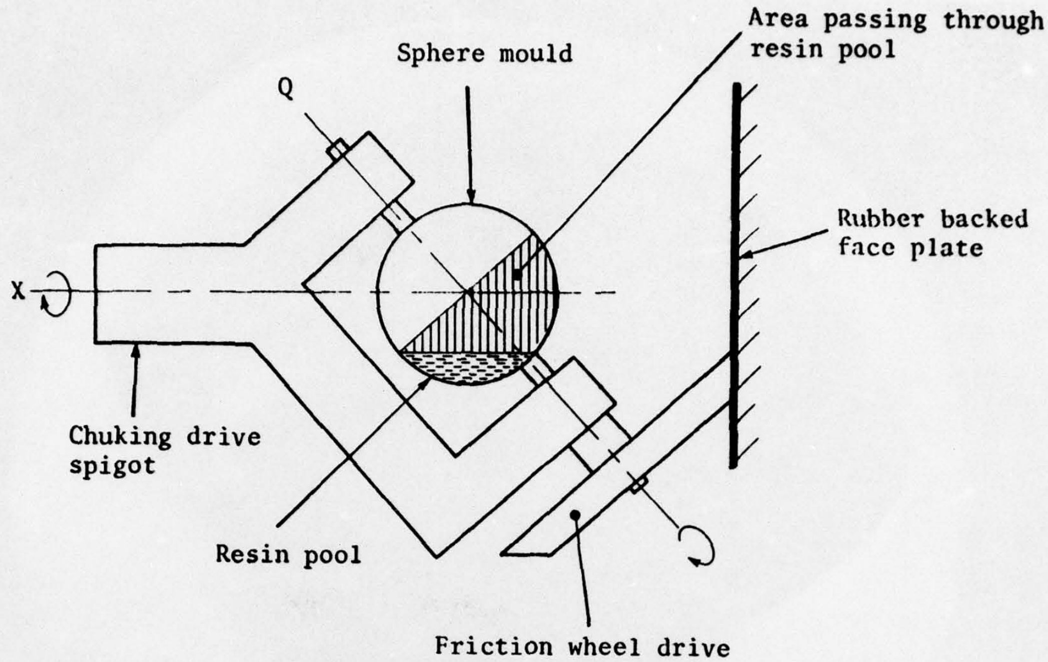

Figure 7(a). Rotation about (Q) axis only: the shaded area passes through the pool of resin

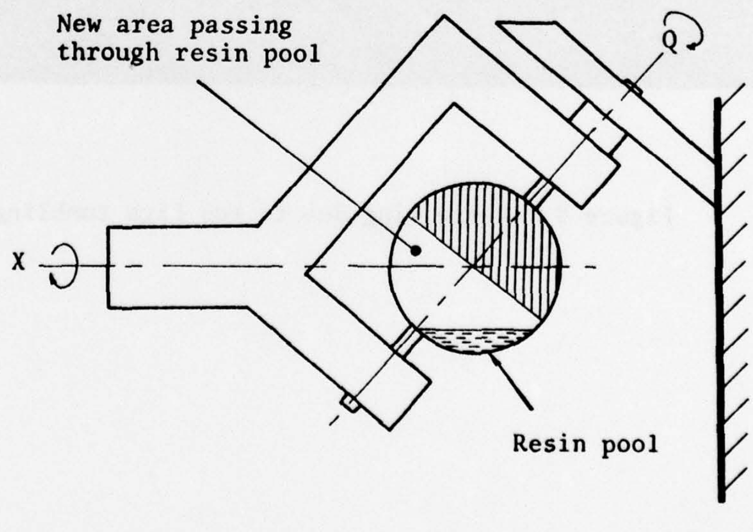

Figure 7(b). Yoke rotated 180^{o} about X axis, rotation about Q axis: unshaded area passes through resin pool

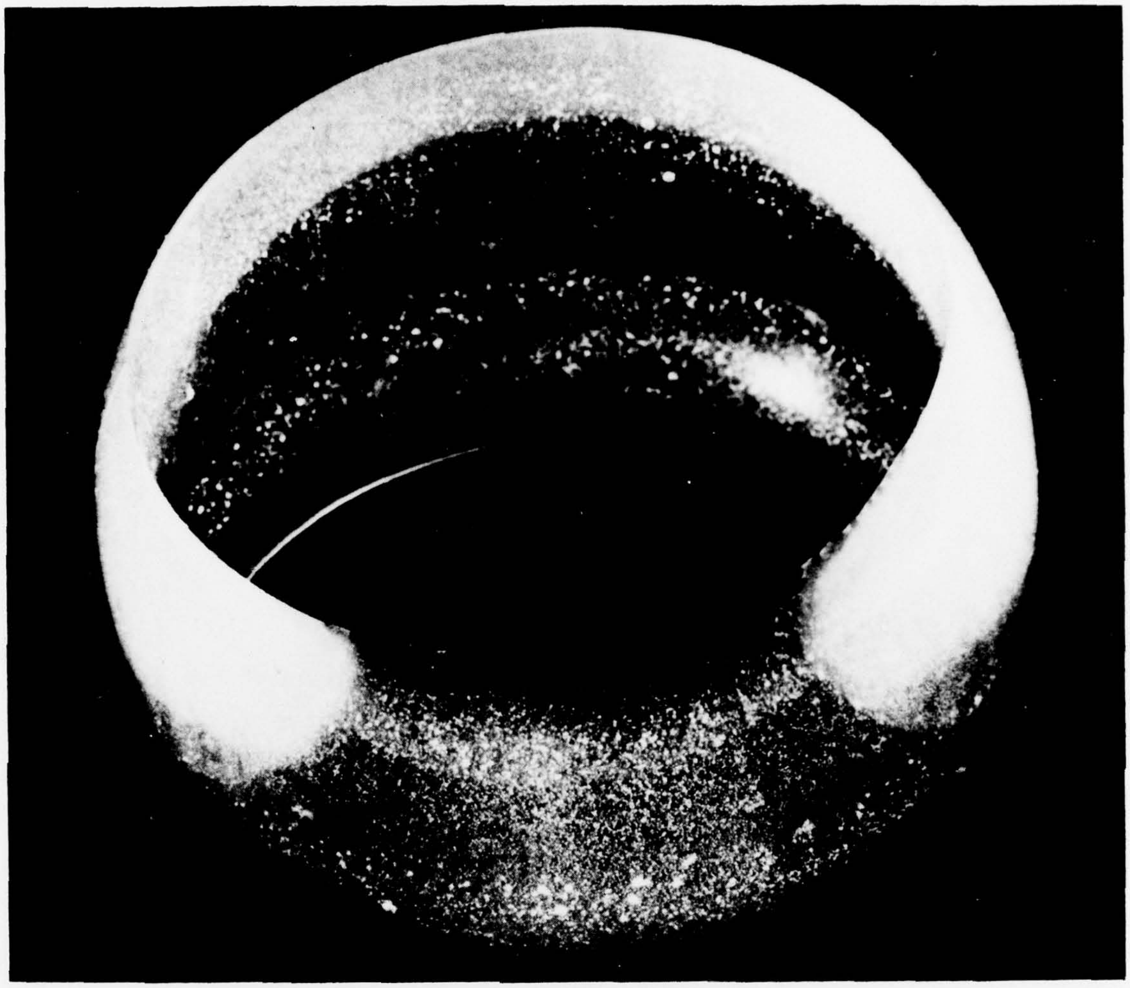

Figure 8. Resin ring due to too high tumbling speed

Figure 9. Resin gel too quick causing snow ball effect on inner surface

Figure 10. Insufficient resin causing incomplete surface coverage

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